# DEFIBRILLATION BY DIRECT AND ALTERNATING CURRENTS AT NORMAL AND REDUCED TEMPERATURES

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Ventricular fibrillation occurs often during hypothermia and open heart surgery. The usual alternating current (AC) countershock reversion is clearly imperfect. Multiple shocks are frequently necessary and at times even these fail. Electrical discharges to the myocardium cause coagulative necrosis, subepicardial hemorrhages, and burns related in degree to the number of shocks (3). In experimental ventricular fibrillation under conditions of hypothermia and acidosis, defibrillation across the closed chest has proved difficult even at discharge levels of 1000 volts.

The direct current (DC) defibrillator * developed by Lown and coworkers has been consistently effective in defibrillating across the intact chest of normothermic animals (1) with fewer undesirable side effects than with AC. This new instrument employs a 16 microfarad capacitor discharging over 2.5 milliseconds, with available energy level range from 0 to 400 watt-seconds (up to 7000 volts).

To evaluate DC defibrillation under conditions of hypothermia, comparative studies were carried out at esophageal temperature levels ranging from 37° C. to 20° C. in closed-chest dogs. Cooling was achieved by an extracorporeal bypass with an oxygenator and heat exchanger. Ventricular fibrillation was induced by single monophasic capacitor discharges synchronized to occur during the vulnerable phase of the ventricular cycle (2). Arterial *p*H, $pCO_2$, Na, and K were determined for each comparative pair of countershocks. Tissue temperatures were recorded by needle thermocouples.

## RESULTS

Defibrillation was attempted in 172 episodes with DC and 137 episodes of ventricular fibrillation with AC. Failure with either of these methods was defined as the inability to defibrillate the heart with

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DC discharges of 400 watt-seconds or with 3 rapidly repeated shocks of 1000 volts (0.15 sec.) each when lesser discharges proved unavailing. DC proved unsuccessful in 2 episodes in a single animal or 1.2%. AC failures were encountered 20 times or 15%. DC countershock restored sinus rhythm in all 20 episodes of AC failure.

Average energy levels for debrillation and the incidence of AC failures decreased. Thus at 20° C. the respective values for AC and DC levels were 900 volts and 200 watt-seconds, while at 37° C. these were 600 volts and 75 watt-seconds. Twelve of the 20 AC failures occurred at 20° C. Low bicarbonate levels consistent with severe metabolic acidosis were the only known constant findings in these failures.

Temperature changes in tissues immediately subjacent to the electrodes revealed *consistent elevations (1° to 2° C.) for each alternating current shock* and this was additive when used in rapid sequence. *DC shocks caused no such temperature elevations.*

DC countershock defibrillation has now been employed in 20 patients after open heart surgery. It has been consistently effective at esophageal temperatures of 24° to 34° C. In the first exposed human heart, DC reversion with a single shock of 30 watt-seconds succeeded, though 12 AC shocks at 250 volts had failed. In another instance after prolonged manual systole a 100 watt-second countershock was delivered directly to the heart ventricles and the patient had an uneventful recovery. The energy levels for reversion have ranged from 20 to 100 watt-seconds. Generally 30 watt-seconds or less suffice when the electrodes are applied directly to the heart. One patient was defibrillated after open heart surgery by external countershock. Successful defibrillation at low body temperatures consistently reduced bypass time.

## DISCUSSION AND SUMMARY

DC countershock has proved to be more effective than AC at all temperature levels despite associated acid base derangements. Direct current discharges caused fewer arrhythmias, less ECG evidence of myocardial damage (1) and less temperature elevation beneath the discharging electrodes.

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# AN EXPERIMENTAL AND CLINICAL STUDY OF A PORTABLE EXTERNAL CARDIAC DEFIBRILLATOR

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In sudden cardiac arrest, first aid external cardiopulmonary resuscitation has been effective in maintaining ventilation and circulation (1, 2). This has increased the importance of adequate definitive treatment in reinstituting spontaneous cardiopulmonary action. Cardiac arrest may occur in ventricular fibrillation as well as asystole or profound cardiovascular collapse. Ventricular fibrillation requires a special procedure to revert it to a coordinated rhythm for which electrical defibrillation has been found to be the most adequate method. Alternating current defibrillators of the internal (low voltage) and external (high voltage) types have been found to be effective. Since ventricular fibrillation may occur beyond the confines of the hospital and away from immediate sources of alternating current, it was felt desirable to see whether a truly portable battery charged type of external defibrillator could be developed.

Extensive studies by Kouwenhoven and Knickerbocker (3) resulted in the development of a 45 pound capacitor discharge external defibrillator which can be charged from 6 or 12 volt batteries or from 115 volt alternating current. Through converters and power packs the low voltage input is stepped up to about 2200 volts direct current and stored in two 25 microfarad capacitors. A 56 millihenry inductor is used in series with the discharge circuit to modify the discharge wave form to give the most favorable defibrillation characteristics. Discharge by a special switch allows a positive charge to be released from the first capacitor followed by a negative charge from the second capacitor. Each pulse is 4 milliseconds in duration with a 6 millisec-

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